The World of Magnetic Recording Media

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The recorded sounds of civilization, in whatever digital or analog fabric they are woven, are destined to remain man's most lasting monument to himself. Visual images will be silent spirits floating across a screen or frozen to paper but they will leave no trail of where they came from or where they have gone. Written words will describe man's beautiful thoughts or will catalog all the knowledge he has accumulated, but will say nothing of man himself. It is only in the records of man, whether of sounds or data, that he can hope to permanently preserve his image. Like human footsteps, the recorded works of man will remain behind him to forever creak softly on the sands of time.

The history of magnetic recording by 3M parallels the history of the industry as a whole. The 3M story is also the story of Wilvred W. Wetzel, who died in 1970 (having retired from 3M in 1963.) Dr. Wetzel contributed more to the development of this technology than did any other scientist. 3M has gone on since then to help perfect and improve the science of recording and playing back the sounds of the universe. This audio and digital technology gives the same permanence to the evanescent sensation of sound that "movie film" gives to sight.

Dr. Wetzel attended the University of Minnesota where he received a B.A. degree in 1928 and a Ph.D. in 1933. He majored in physics with a minor in mathematics. During the early thirties, Dr. Wetzel published papers on the quantum mechanical treatment of ionization phenomena. From 1933 to 1936 he taught physics at Colgate University. The 1936-1937 academic year was spent at Massachusetts Institute of Technology as a student of applied geophysics. From 1937 to 1940 Dr. Wetzel taught exploration geophysics at the University of Minnesota and at the University of Chicago. These courses covered the theory and practice of seismic, gravitational, electric and magnetic methods of mining.

In 1940 Dr. Wetzel accepted a position with the Naval Bureau of Ordnance for work in connection with the protection of ships from magnetic mines. This later evolved into studies on detecting and recording underwater sounds. Through this work Dr. Wetzel became acquainted with magnetic recording methods.

He joined 3M in 1944 as head of the physics section of the central research department. This section was assigned the task of developing magnetic materials.

Toward the close of World War II, a core of Allied scientists was sent to Germany to investigate and bring back a highly developed magnetic tape and tape recorder system for general recording purposes. 3M Company, already a large producer of a variety of pressure-sensitive tape products, immediately began an intensive development program aimed at supplying the motion picture and broadcasting industries with this new recording tool.

In 1948 Dr. Wetzel was appointed Technical director in charge of the laboratories of 3M's newly formed magnetic recording division.

His work in magnetic film manufacture, oxide development, bias theory and his pioneering achievements in the theory of magnetic sound have been most significant.

The life and contributions of Dr. Wetzel are a single chapter in the chronology of events that have marked the emergence of the magnetic-media-for-recording industry. Other bright moments out of the past follow. In 1880 William Hedic introduced a method of fixing magnetic particles to tape. In 1888 Oberlin Smith described his first successful attempts to produce magnetic recordings. In 1893 V. Poulson demonstrated a magnetic wire recorder. In 1908 Edison introduced his Amberol cylinder. In 1921 Max Kohl unveiled a magnetic recorder with built-in tube amplifier and steel disks for dictation. In 1927, Fritz Pfleumer glued iron oxide onto strips of paper. In 1933, BASF working with Pfleumer, produced magnetic tape. In 1935 BASF perfected a process for coating tape and the Berlin Radio Exhibition in that same year, featured a demonstration of a tape recorder. In 1936, Sir Thomas Beecham made the first serious musical recording on magnetic tape. In 1938, German Radio stopped using discs for recording sessions and switched to tape. In that same year, Brush Soundmirror introduced US to steel tape. In 1939 Bell Telephone demonstrated stereo recording with steel tape at the World's Fair. In 1941 Marvin Camaras got a patent for AC bias in magnetic recording. In 1944 Ralph Oace of 3M began experiments with tape coatings. In 1946 GE patented a magnetic phonograph cartridge. In 1947, Ampex introduced a tape recorder as its first post-war product. In 1949 Magnacord introduced a stereo tape recorder. In 1950, VOX offered the first commercially recorded tapes. In 1953 three

companies (3M, Ampex and RCA) demonstrated color videotape. In 1954, Audiosphere marketed the first stereo tapes. In 1979 this author paid a visit to 3M's Data Recording Products Division at Weatherford, OK.

Oklahoma, as you look down at it from the window of a plane, is nothing like Rogers and Hammerstein's stage musical. You are awed by the power of simple landscape design lying below. Large areas of flat country run all the way to the horizon. The earth has been cut up into neat checkerboard designs of large patches alternating in color between iron-ore red and vegetative shades of green. Neatness of the countryside is its most striking feature. When you land, you are not greeted by Rogers and Hammerstein's dancing and whooping cowboys. Instead, plant manager George Olson, dressed in a natty sports outfit and wearing a colorful necktie that suggests collegiate colors, walks out to the center of a lonely, single-runway airstrip to greet us upon arrival. He is a tall, warm, smiling ambassador from the 3M company and looks athletic enough to play wide end for the Dallas Cowboys.

The 3M branch, in this isolated great Oklahoma plain, is a modern plant laid out on closely-cropped grass surroundings and with very few windows. It is air conditioned and squeezes its incoming air supply through dust cleaning filters. Inside the building everything is hospital clean. Even the floors have been painted in a clear, shiny polyurethane finish so that it looks like glass. The reason for the lack of windows and the filtering of air and the cleanliness of the area is the threat of outside contaminants trying to get in and endanger the constantly monitored clean environment. The contaminants are like viruses trying to penetrate the defenses of the human body. Dirt and contaminants are the chief enemies of magnetic coatings and a tiny dust particle, visible only under an electronic scope, when impregnated to the surface of a 14″ rigid disk, can, for the end user, wipe out some vital information or delay access times. So, 3M's constant, unending struggle, we were soon to find out, was its ceaseless battle against contamination. It is not an easy task. The human body itself, and there are about 600 permanent employees at the plant, is a factory of contamination. Each body produces five or 6 pounds of such microscopic particles daily. Those particles have to be picked out of the air before they land on disk surfaces. In this fight against contamination, 3M performs all vital operations within closed, atmosphe-controlled systems. Every completed operation is carefully tested to remove any contaminants that have landed during the process. Fifty percent of the 3M floor equipment produces the magnetic-media product; the remaining 50% of equipment has the vital function of quality testing every result. Most test instruments in the plant have been developed by 3M workers, and many of the commercial testers have been modified to do a special job in surface scrutiny and correction. Some tests are simply measurements that check conformity to prescribed parameters. Other tests are more exotic. Tests on the aluminum substrate of the 14″ disks, for example, will ensure that the finished plate will be "perfectly" flat. An oscillating sensing head, riding a microscopic distance above the "flat" surface can smash into a tiny bump and the collission could produce serious data destruction and computer shutdown. So the platters are rubbed, scrubbed, abraded and polished until test equipment indicates there is no unacceptable deviation from "flatness". The primary goal of 3M, says a spokesman, is to turn out a disk so perfectly level that no problems will ever vex the future end-user as the disk spins at around 150 mph on its permanent axis. The same hen-over-chick worry is applied by 3M to its jealously garded coating process. The liquefied ferrous oxide (plus other ingredients) are carefully flowed over mirrored aluminum disks and then polished until the operator can see his own image in the surface. This "secret" process is done behind closed doors (barred to everyone except cleared employees) and in a sealed environment. It is the most sensitive of all processes at this Weatherford plant. Company officials like to say, in their feigned cowboy twang and while wearing their happy-hour 6″-brim rolled Stetsons, "our secret isn't in the ferrous oxide formula we use. It's in the way we use it! We've spent a lot of time and money in perfecting this process and becoming No. 1 in the Data Recordings Product field. And we just don't feel like telling our competitors how to do it." Obviously, the success or failure in producing an acceptable disk for magnetic data recording is highly dependent on this particular coating process.

Once the coated disk has left the "secret room" it goes through a series of automatic cleansing baths designed to free the surface of any clinging microscopic-sized debris.

When the disk emerges from its "Roman bath" it then undergoes other procedures to assure that its critical outside and inside diameters are correct. It is also dynamically balanced so that it will not wobble as it spins at high speed. Then the final polishing and testing begins. When acceptable disks emerge from the assembly line, they are then sectioned and formatted and given a final test. They are sealed in rigid-disk cartridges and sent to the shipping platform. The 5″ minifloppies and other forms of magnetic media designed for computer use are treated similarly. In anticipation of the developing market for the new 8" hard disk, 3M has already "tooled up" and will be ready to meet commercial demand for that product. The 8" is already being hailed as indicative of the revolutionary changes beginning to appear in computer architecture. After the plant tour we had a chance to put some questions before 3M's supervising team. Digital Design, in the following dialogue, is interviewing Al Smith, Don Tomisak, Allen Fobes, Marv Glanzer, S.C. Kretzschmar and others.

They all have different functions at this division and their individual remarks here are listed as group responses.

DD: How long will computer technology regularly keep producing new products?

3M: People have wondered for years about that question. I think this technology will still be growing, with new products still being introduced, well beyond the 1990's.

DD: What can we expect from tomorrow's research?

3M: Industrial and university labs have already shown that we will be recording at densities 15 times greater than those in use today.

DD: Will there be any problems with such packed density techique?

3M: The implications are vast. Magnetic media will be able to store enormous emounts of information. The biggest problem will be retrieval of this information. As a result you can expect to see many new design parameters for drives and other hardware devices. We will be tailoring our own media packages to accomodate these new devices. There will be various cart-

ridges and cassettes and packs and stacks of cards and disks of unimagineable descriptions, for use on these new devices.

DD: What about thin film technology?

3M: This new techology will be used for recording very high densities – greater than 20,000 bpi. This will be primarily on rigid substrates because of physical constraints. We will see heads as the first to be effected by thin film. After that, media developments will take place. Activity in this field should start occurring in the next two years.

DD: What about optical technology?

3M: By the mid-80's optical technology will be included in many computer systems. Right now, magnetic technology is cheaper. The practical recording limits are the same, we feel, for both optical and magnetic technology. We will be able to achieve the same recording densities with magnetic techniques that will be possible with optical. Laser technology, on the other hand, could conceivably change that picture.

DD: What product does 3M find most in demand today?

3M: Computer tape has been our bread and butter product for years and is still the largest part of our business. For a while we thought computer tape would decline in favor of disk systems. It turns out that that didn't happen. Disk systems require back-up and tape is unbeatable for archival purposes. Tape is alive and doing well and we expect it to be around for a long time to come.

DD: What about diskettes? Are we seeing their slow demise?

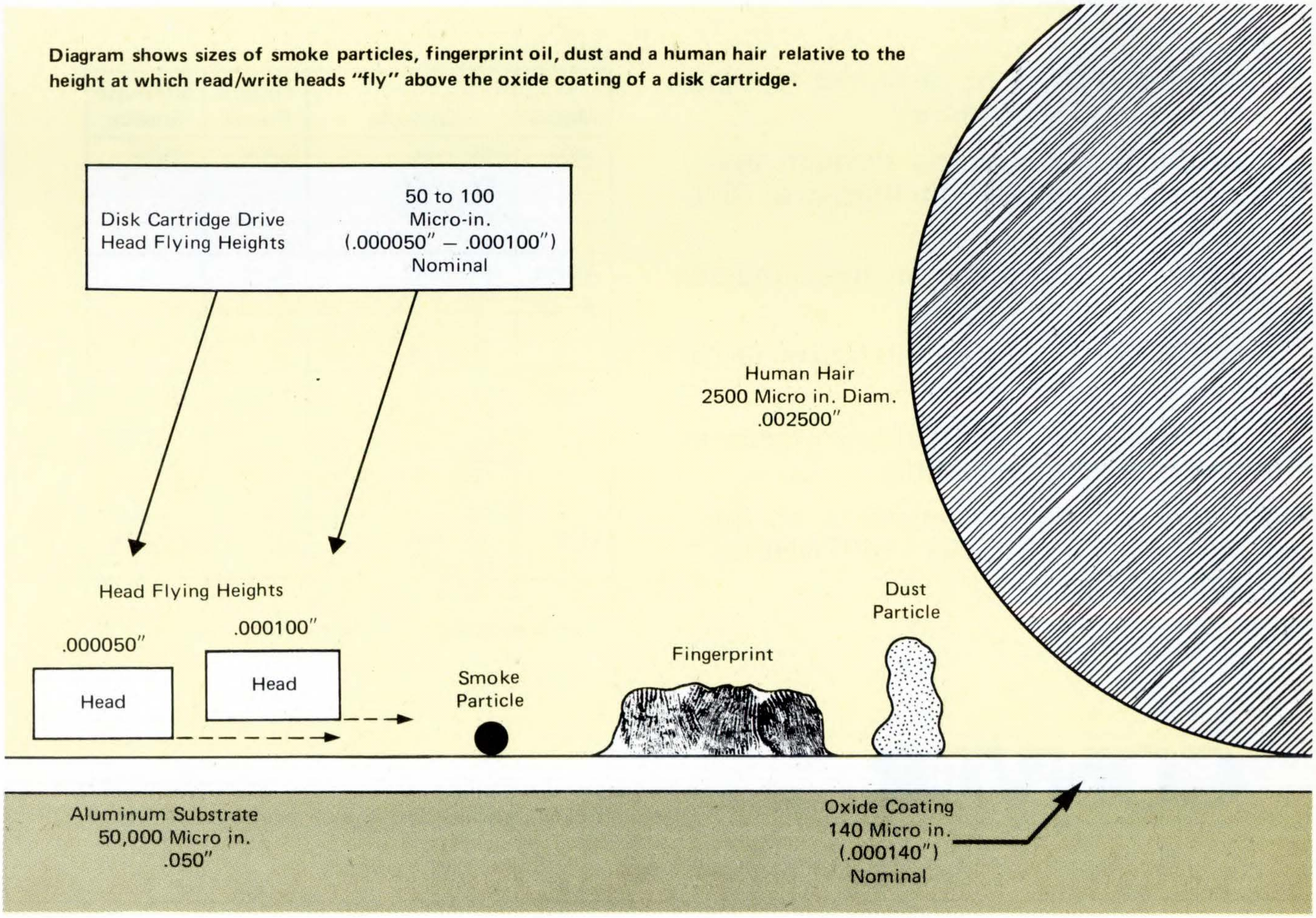
3M: Not yet. As Mark Twain said, reports of their death are premature. Diskettes are going krazy. Pick your own number as far as growth is concerned. There are a lot of estimates being knocked around. Minicomputers are expanding at the growth rate of 30% a year and micros are expected to far exceed that. A good comparison to make is that diskettes will be bigger than tape, one day soon, measured on a dollar basis. Also, consider these facts: a roll of computer tape that is sold to a distributor for $11 required 11.1 square *yards* of magnetic coated material. A diskette, which will sell from $2.25 to $4.40, at today's prices, requires less than one square *foot* of magnetic coated material. The roll of tape sells for 2½ to 5 times more than a diskette but uses 100 times more magnetic coated material.

DD: What is the projected market growth for disk products over the next few years?

3M: Our own business here is very good, as you've undoubtedly noticed on the plant tour. The market growth potential as we see it is in between the mild and wild – 15% to 20% annually is probably a pretty good figure.

DD: What is happening in the marketplace and how is the 3M preparing for any changes?

3M: There is an increased shift, now, toward distributor marketing. With the advent of distributed processing and the minicomputer explosion, the market changed from one that was narrow, specialized, highly visible and easy to cover, to one that was dispersed, fragmented, difficult to find, and costly to cover. We have shifted our resources from a division that was essentially a direct industrial sales organization to one that is selling increasingly through distributors and OEM accounts. As an example, in 1974 85% of 3M's business in this



product was on a direct basis with the remaining 15% being sold through distributors or OEM accounts. By 1983 direct sales will be around 15% and sales through distrutors will be at the 85% mark. This change is dramatic when you add our projected growth estimates on top of it.

DD: The number of quality tests that 3M does in this plant are impressive. Can you explain some of them?

3M: Measurements of all quality acceptance parameters are measured by our own production operators. We don't have special people doing the testing. The logic that 3M uses behind such a quality system is the pride that it places in each of our operators. They can see for themselves the specification requirements and also the exact workmanship that they have just completed. We feel that this has been 3M's strongest asset for achieving quality uniformity throughout our manufacturing operation. Even the majority of all test equipment is built by our own 3M people. However, some various test-measurements equipment is then modified to measure the responses that we feel are necessary. The majority of our tests are defined and characterized by our people.

DD: Can you give an example of one of your more complicated test procedures.

3M: The "TVA Test" would be such an example. The term, TVA, is derived from 1) "total indicated runout", 2) velocity; 3) acceleration. Some of the tests made at this single station of our operations is measurement of the vertical change of velocity with respect to time; the displacement perpendicular to the disk surface; local variation in disk thickness; variation of a surface above or below a reference plane; surface roughness measurement; the absolute measurement of difference between top and bottom surfaces; vertical velocity-change measurement.

DD: What are some of the contaminants that could affect disk performance?

3M: The single most common debris that a human body throws off is dead skin cells; other contaminants associated with people are saliva, hair and finger prints (which are mainly composed of body oil.) The fingerprint ultimately becomes a collecting point for other microscopic particles. The clothing worn can also be a source of debris in the form of cloth fibers and dust. To determine how large a contaminant a disk can tolerate, one must know the flying height of the recording head. This determines the size of a contaminant or a particle which may be tolerated by the head. Examples:

Product Type	Height of Flying Head	Maximum Tolerable Size of Particle
6 High Disk Pack	100 μ''	70 μ''
11 High Disk Pack	80 μ''	50 μ''
Winchester Disks	19 μ''	13 μ''
SMD 80 MB Pack	35 μ''	23 μ''

DD: What is the most critical test done at the Weatherford plant?

3M: Servo surface acceptability following servo writing. The test equipment itself is on a marble base and the chamber is air-conditioned.

DD: Describe the dozen or so cleaning baths used on the disks moving on the assembly line and applied just before the coating operation.

3M: The baths are, basically for surface preparation. The details are not discloseable. In general, though,

various chemicals are used to clean and treat the surface to assure strong adhesion of the magnetic coating.

DD: Most of the tests at Weatherford were for the 14″ rigid disk. How many tests, by comparison for the 5″ floppy?

3M: Though critical flatness tests are not as vital for the flexible disks, they do receive the same degree of product attention. Counting all stages, including visual inspection, the flexible disks must be evaluated at 63 different points in the process.

DD: How much of a physical task will it be to switch from 14″ disk production to accommodate 8″ hard-disk manufacture?

3M: Most of the 3M-designed production equipment was designed so that conversion from 14″ to 8″ production will be a relatively easy one. Basically, the structure and process are similar for both sizes.

DD: How flat are the 3M disks? Your company apparently spends a lot of time in turning out a perfectly flat product. An old law of physics says that if you put two perfectly flat surfaces against each other, they will become inseparable, due to vacuum and atomospheric pressure.

3M: Our disks typically exhibit a surface roughness of only about 1 μ''. This surface finish in combination with the overall flatness of the disk could result in disk to disk wringing if the two surfaces were ever placed in contact with each other.

DD: How long can you expect a 3M disk to last when in actual use?

3M: If the disk is not physically damaged by handling or in operation it can last indefinitely. Typical design requirements are 50,000 stop-start cycles (head load) without surface deterioration. This equates to an operator mounting a disk pack or cartridge five times a day for over 25 years.

DD: What are some of the problems encountered with OEMs and with END users?

3M: End user problems relate to improper care and handling. Customer education concentrates largely on resolving the many problems that occur on a daily basis. In the OEM area problems arise in applying state-of-the-art technology. Application of this technology to the head, disk and drive interface requires close coordination between development, manufacturing and the OEM customer.

DD: What is the top spin speed for 3M disks and how fast a reading-head movement can be designed to travel across the moving disk?

3M: Industry disk usage, as well as 3M, is typically 3600 RPM. Single disks have been experimentally spun up to 6000 RPM without apparent degradation to the disk. Factors to be considered when designing a high-speed positioning system are the aero-dynamic characteristics of the head, accelerating-decelerating forces from track to track positioning and the dynamic flatness characteristics of the media.

DD: Can you list the increase in storage capabilities of disks during the 10 years and can you predict similar such increases in the next ten years?

3M: This chart is self explanatory.

Year	BPI	×	TPI	≈	Areal Density (mbits/sq. in.)
1966	1100		100		.11
1970	2200		200		.44
1972	4040		192		.77
1974	4040		370		1.49
1976	6060		384		2.32
1977	6350		478		3.04
1978	8530		450		3.84
1979	6550		714		4.68
1980	8000		960		7.68
Future	15000		1200		18.00
Future	18000		1600		28.80
Future	25000		2000		50.00

DD: What has happened to the costs of data storage and retrieval over the years?

3M: In 1955 the cost per megabyte in main memory was \$8.5 million. By 1985 this main memory cost per megabyte will have dropped to less than \$7 thousand. Auxiliary storage, for the same time period was \$6.7 thousand per megabyte in 1955. That will drop to an estimated \$25 or \$30 by late 1980.

DD: What will the world of data processing be like in 1990?

3M: The trends toward miniaturization and areal density compaction that have occurred in the past 10 years will probably occur at the same rate during the next decade. Advances in information systems' reliable storage capabilities will continually occur, with media of all kinds possibly involved – magnetic or otherwise. The interaction between media technology and systems designers is vital; the ability to create more advanced designs will inexorably be related to advances in information storage – both media and systems. It's a moving target which will keep on moving. Everything will be growing. The Encycolpedia Brittanica contains 433 million words. If each word averages five characters, it contains two billion 165 million characters (each carried by a byte of data). Thus, it would now take 108 disks to hold the entire 30-volume set. When capacity is quadrupled in the future, it will take 27 disks. But, disks do not necessarily have massive storage capacities; their major contribution is rapid access to data. And that speed is increasing constantly.

DD: In the overall production of magnetic recording media, how many different types of each are currently being produced in the entire country by all the manufacturers?

3M: Rigid disks, 5.3 million; diskettes, 40 million; tapes, 9 million (on standard length computer reels.)

DD: If you could convert that annual production volume into one large disk, how big would it be and how much data could be recorded on it?

3M: The disk would be about 6.4 miles in diameter. Based on the content of a 30-volume set of Encyclopedia Brittanica (433 million words) and assuming an average of five characters per word, about *1/4 billion sets* of the encylcopedia could be stored on that combined magnetic medium. This means solid recording – no spaces or allowances for format or retrieval.

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